

APPLICATION NO. 09/826,118

TITLE OF INVENTION: Wavelet Multi-Resolution Waveforms

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Currently amended CLAIMS



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INVENTORS: Urbain A. von der Embse

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## CLAIMS

WHAT IS CLAIMED IS:

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Claim 1. (deleted)

Claim 2. (deleted)

Claim 4. (deleted)

Claim 5. (deleted)

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Claim 6. (deleted)

Claim 7. (currently amended) A least-squares method for  
~~implementing~~generating and applying mother Wavelet waveforms and  
~~filters for communication applications,~~ said method comprising  
20 the steps: steps:

said ~~mother Wavelet~~Wavelet  $\psi(n)$  with ~~sample index n~~ is a digital  
finite\_impulse response (FIR) ~~—~~ waveform at baseband ~~(zero~~  
~~frequency offset)~~ in the time domain,

~~requirements for linear phase FIR~~finite impulse response

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~~—filter requirements are specified by on —~~ the passband and  
stopband performance of the power spectral density \_\_\_\_  
~~(PSD) which requirements are incorporated into~~specified by  
linear quadratic error metrics  $J(\text{pass})$ ,  $J(\text{stop})$ , in the  
Wavelet,

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~~Wavelet~~Wavelet ~~—~~ requirements on the deadband for

~~—quadrature mirror filter (QMF) properties for required~~  
for perfect reconstruction are incorporated specified by  
into the a linear quadratic error metric  $J(\text{dead})$ , in the  
Wavelet,

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~~Wavelet~~Wavelet orthogonality requirements are ~~expressed by the~~

~~error  $J(\text{ISI})$ ,  $J(\text{ACI})$  for intersymbol interference (ISI)~~  
~~and adjacent channel interference (ACI) which are~~  
specified by non-linear quadratic error metrics in the  
Wavelet,

5 non-linear quadratic error metrics have in said FIR  $\psi(n)$  used to  
~~control said ISI and ACI levels,~~ quadratic coefficients  
dependent on the Wavelet,

Wavelet multi-resolution property requires said ~~quadratic error~~  
metrics to be converted to ~~quadratic error~~ metrics in the  
10 ~~discrete Fourier~~ Fourier transform harmonics  $\psi(k)$   
~~of said  $\psi(n)$  wherein  $k$  is the harmonic index of the Wavelet~~  
which harmonics are the Wavelet impulse response in the  
frequency domain,

using a least-squares recursive solution eigenvalue algorithm  
15 algorithm in figures 4,5 with quadratic error metrics,  
which algorithm requires a means to find the Wavelet  
harmonics that minimize the sum of said linear quadratic  
error metrics, an example means being the eigenvalue  
algorithm,

20 ~~requires the error metrics to be linear forms in the  $\psi(k)$~~   
~~finds the eigenvectors equal to the  $\psi(k)$  coefficients which~~  
~~minimize the weighted sum  $J$  of said quadratic error~~  
~~metrics,~~

~~step 1 of the iterative algorithm~~  
25 ~~implements said eigenvalue~~  
~~algorithm to find said optimum  $\psi(k)$  for the weighted~~  
~~sumsum of  $J(\text{pass})$ ,  $J(\text{stop})$ ,  $J(\text{dead})$ ,~~

~~step 2 linearizes said  $J(\text{ISI})$ ,  $J(\text{ACI})$  with said  $\psi(k)$  from step~~  
~~1, said harmonics are used to linearize said non-linear~~  
30 quadratic error metrics,

said least-squares recursive solution algorithm finds the  
harmonics which minimize the weighted sum of the linear and  
linearized quadratic error metrics,

~~step 4 checks to see if said iteration has converged,~~

said least-squares recursive solution algorithm starts over  
 again by using said harmonics to linearize the non-linear  
 error metrics and to find the corresponding harmonics which  
 minimize the sum of said linear and linearized quadratic  
 error metrics,  
 said least-squares recursive solution algorithm continues to be  
 repeated until the solution converges to the design  
 harmonics of the Wavelet which is the least-squares error  
 solution, and  
 said Wavelet impulse responses in the time domain and  
 frequency domain are implemented in communication systems  
 for waveforms and filters.  
~~step 5 returns to step 2 if said iteration has not converged and~~  
~~linearizes said  $J(\text{ISI})$ ,  $J(\text{ACI})$  with said  $\psi(k)$  from step 4,~~  
~~and stops iteration if said iteration converges,~~  
~~said  $\psi(k)$  from said iteration algorithm is the optimum least-~~  
~~squares error solution that minimizes said  $J$ ,~~  
~~use inverse discrete Fourier transform of said  $\psi(k)$  to calculate~~  
 ~~$\psi(n)$  which minimizes  $J$ ,~~  
~~use said  $\psi(n)$  for the transmitted data symbol waveform in the~~  
~~communications transmitter and,~~  
~~use complex conjugate of said  $\psi(n)$  for the impulse response of~~  
~~the detection filter in the communications receiver to~~  
~~remove the received  $\psi(n)$  and recover said transmitted data~~  
~~symbols.~~

Claim 8. (currently amended) ~~A second~~ A second method for  
least-squares method for generating and applying Wavelet  
waveforms and filters, said method comprising the steps:  
~~implementing mother Wavelet waveforms and filters for~~  
~~communication applications, said method comprising~~  
~~construct said error metrics  $J(\text{pass})$ ,  $J(\text{stop})$ ,  $J(\text{dead})$ ,  $J(\text{ISI})$ ,~~

~~J(ACI) as quadratic error metrics in  $\psi(k)$  as depicted in claim 7 and convert these quadratic forms to norm-squared error metrics in  $\psi(k)$  for least-squares gradient solution and construct J as their weighted sum,~~

5 linear phase filter requirements on the passband and  
stopband performance of the power spectral density are  
specified by linear quadratic error metrics in the Wavelet  
impulse response in the time domain,

10 using a least-squares recursive solution algorithm in figures 4,5  
with norm-squared error metrics, which algorithm requires  
a initialization Wavelet and a means to find the Wavelet  
harmonics which minimize the sum of said linear norm-  
squared error metrics, an example means being a gradient  
search algorithm,

15 ~~step 1 calculates an initial estimate  $\psi(k)$  of said solution~~  
~~using~~

said initialization Wavelet is the Remez-Exchange algorithm  
optimum Wavelet that minimizes the weighted sum of said  
linear quadratic error metrics which optimum Wavelet is  
20 found using an eigenvalue, Remez-Exchange, or other  
optimization algorithm,

~~for the weighed sum of~~

~~J(pass), J(stop) represented as quadratic error metrics in~~  
 ~~$\psi(k)$ ,~~

25 said linear quadratic error metrics are transformed into linear  
norm-squared error metrics in the Wavelet,

Wavelet requirements on the deadband for quadrature mirror  
filter properties required for perfect reconstruction are  
specified by a linear norm-squared error metric in the  
30 Wavelet,

Wavelet orthogonality requirements for intersymbol interference  
and adjacent channel interference are specified by non-  
linear norm-squared error metrics in the Wavelet,

~~step 2 uses said estimate  $\psi(k)$  from step 1 to initialize said~~

~~gradient algorithm,~~  
step 3 selects one of several available gradient search  
~~algorithms, gradient search parameters, and stopping rules,~~  
step 4 implements said algorithm, parameters, and stopping rule  
5 selected to derive said optimum  $\psi(k)$  to minimize J equal to the  
weighted sum of the norm squared error metrics J(pass), J(stop),  
J(dead), J(ISI), J(ACI),  
non-linear norm-squared error metrics have norm coefficients  
dependent on the Wavelet,

10 Wavelet multi-resolution property requires said error metrics to  
be converted to error metrics in the discrete Fourier  
transform harmonics of the Wavelet which harmonics are the  
Wavelet impulse response in the frequency domain,,  
using said least-squares recursive solution algorithm to find the  
15 harmonics that minimize the weighted sum of said least-  
squares linear and non-linear norm-squared error metrics,  
which harmonics are the design harmonics of the Wavelet  
least-squares error solution, and  
said Wavelet impulse responses in the time domain and  
20 frequency domain are implemented in communication systems  
for waveforms and filters.

use inverse discrete Fourier transform of said  $\psi(k)$  to calculate  
 ~~$\psi(n)$  which minimizes J,~~  
use said  $\psi(n)$  for the transmitted data symbol waveform in the  
25 ~~communications transmitter and,~~  
use complex conjugate of said  $\psi(n)$  for the impulse response of  
the detection filter in the communications receiver to  
remove the received  $\psi(n)$  and recover said transmitted data  
symbols.

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a) Claim 9. (deleted)

Claim 10. (currently amended) ~~A method for~~  
~~implementing~~ Wherein applications of the Wavelet waveforms and  
filters for multi-resolution communication applications derived  
from said mother Wavelet in claims 7 or 8, s in claims 7 or 8,  
5 comprising: steps:  
~~said mother Wavelet is designed for application to an M~~  
~~channel polyphase filter bank as depicted in claims 7 or 8 wherein~~  
Wavelet design in the frequency domain allows a mother Wavelet to  
be re-scaled for application to multi-channel polyphase  
10 filter banks by implementing equations (11), (18), (20) which  
derive a multi-resolution Wavelet from a mother Wavelet by  
using the design harmonics of the mother Wavelet and the  
multi-scale parameters of the Wavelet impulse response for  
said application,  
15 wherein mother Wavelet refers to a Wavelet at baseband which is  
used to generate other Wavelets,  
wherein multi-scale parameters are the traditional scale,  
translation, timing parameters, plus the new frequency,  
spacing, and length parameters of this invention,  
20 scale parameter scales the sampling time interval, the sub-  
sampling, the over-sampling, and the translation interval  
between Wavelets,  
translation parameter is the timing offset of the Wavelets in  
units of the spacing parameter,  
25 timing parameter is the digital sampling interval,  
frequency parameter is a frequency offset which translates the  
Wavelet in frequency,  
spacing parameter is the number of digital samples for Wavelet  
spacing which is equal to the number of channels in a  
30 polyphase filter bank with a Nyquist sampling rate,  
length parameter specifies the length of the Wavelet in the  
sampling domain, and  
said multi-scale parameters and the mother Wavelet design  
harmonics generate the Wavelet for the multi-channel  
35 polyphase filter bank.

5 ~~M is the spacing between Wavelets within said channels for~~  
~~the Nyquist digital filter bank sample rate  $1/T$ ,~~  
~~said multi-resolution changes the number of said user channels~~  
~~to  $M2^p$  while keeping the same channel filter design which~~  
~~means said Nyquist digital sample rate is changed to~~  
 ~~$2^p/T$  wherein Wavelet scale parameter  $p$  is an integer,~~  
10 ~~said multi-resolution Wavelet FIR  $\psi(n)$  is derived from said~~  
~~mother Wavelet design harmonics  $\psi(k)$  using the inverse~~  
~~discrete Fourier transform for the mapping of  $\psi(k)$  to  $\psi(k)$ ,~~  
~~use said  $\psi(n)$  for the transmitted data symbol waveform for each~~  
~~transmit channel in the communications transmitter and,~~  
15 ~~use complex conjugate of said  $\psi(n)$  for the impulse response of~~  
~~the detection filter bank in the communications receiver~~  
~~which is used to remove the received  $\psi(n)$  and recover said~~  
~~transmitted data symbols.~~

20 Claim 11. (deleted)

Claim 12. (newcurrently amended) Wherein said  
25 Wavelet properties of Wavelet waveforms and filters in claims 7  
or 8, in claims 7, 8, or 10 have properties comprising:  
said multi-resolution Wavelets are multi-resolution Wavelets which  
enable a single Wavelet design at baseband to be used to  
generate Wavelets  $\psi(n)$  at baseband are derived from  
30 said mother Wavelet Wavelets for multi-resolution  
applications by implementing equations (11), (18) (20) and  
using said the Wavelet design harmonics harmonics  $\psi(k)$  and  
the multi-scale scale parameters for the multi-resolution



~~Wavelet applications, said dilation p, said number of samples M over Wavelet spacing, length (L) in units of M, said digital sample rate 1/T, and translation parameter.~~

5 ~~said  $\psi(n)$  Wavelet can be designed to support a bandwidth for a communications waveform with (B) time (T) with no excess bandwidth  $\alpha=0$ ,~~

10 ~~said multi-resolution Wavelet Wavelets are designed to behave like an accordion in that at different scales said the Wavelets are is a stretched and or compressed versions of the mother Wavelet Wavelet with appropriate time and frequency translation, as disclosed on page 21,~~

15 ~~said linear waveform and filter least-squares design methods can be modified to design non-linear Wavelet waveforms for other applications including bandwidth efficient modulation and synthetic aperture radar as demonstrated in figures 7, 8, and,~~

~~other optimization algorithms exist for finding said Wavelets. optimum  $\psi(n)$ .~~